Gathering data on muon formation in the upper atmosphere, creating a model of a slice of the Earth's magnetic field, testing the dampening properties of honey, hair gel and Jell-O, and promoting interest in STEM fields with a local middle school.

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1.0 Mission Statement

The first goal of the payload is to continue collecting data about muon flux in the Earth’s atmosphere. The second goal is to continue with a second heritage element, a magnetometer. It is used to collect more data about the Earth's magnetic field at different altitudes. The final subsystem and only new one was used to measure the vibration damping properties of common materials. The vibration dampening materials used are Jello, honey, and hair gel. The last goal is to run an outreach program to the local middle school again.

2.0 Mission Requirements and Description

The payload was designed around the following requirements, as laid out by the RockSat-C User Guide and Colorado Space Grant Consortium:

Payload Physical Envelope: The payload was required to fit into the bottom half of a 9.3” diameter, 9.5” tall cylinder, with Stevens Institute of Technology occupying the top half the cylinder. The HWS payload fit in a 9.3” diameter, 4.75” tall cylinder.

Weight Requirement: The payload (in combination with the Stevens Institute of Technology payload) was required to weigh 20 ±0.2 lbs when integrated into the canister. The mass of half a payload without the canister should be 6.67 lbs ±0.1.

Center of Gravity: The payload (in combination with Stevens Institute) was required to have its center of mass within a 1 x 1 x 1 inch cube at the geometric centroid of the payload canister. In order to achieve this, the bottom and top payloads were designed such that its center of gravity was within a ½ x ½ x ½ inch cube in the geometric centroid of the respective half of the canister. When the two halves were placed in the same canister, the horizontal component of the center of gravity would cancel one another out and the overall center of gravity would fall according to the design requirements.

Electrical Requirement: The payload was required to be able to be activated by NASA using a T-3 switch. In order to enable this the power supply consisting of four 9 volt Alkaline batteries, are connected in parallel. Teflon coated activation wires led from the canister to activate the payload. Additionally, the canister skin is required to have no voltage running through it, which required all components to be well insulated. Finally, no voltage above 34 volts was permitted. The peak voltage from the power supply is 9 volts.

Current Requirement: The T-3 activation lines were required to have less than 1000 mA of current flow when the payload is activated. Additionally, the canister skin was required to source no current. The peak current measured from the payload was 351 mA.

Structural Stability: The mounting plate and top plate are made of plastic. The standoffs are made of aluminum with lead cylinders inside to help achieve the weight requirement. The muon detector and its electronics, the batteries, and the accelerometers encased in the
various gels are contained in 3D-printed PLA plastic components which are screwed onto the mounting plate. The Arduinos for the magnetometer and the vibration dampening system are screwed directly to the mounting plate with plastic screws. Hot glue is used to adhere these screws to the plate and 3D printed mounts to ensure that they would not come loose in testing or flight. This method has been successfully used by the HWS teams in past years.

In order for the payload to be quickly and easily added or removed from the canister, all experimental components were designed to be mounted to either side of a central plate, which itself could be mounted via standoffs to the bottom plate of the payload canister.

The mission requirements for the payload are for the sensors to work as intended. For the muon detector this means that it should register muon counts as the rocket increases in altitude. The magnetometer will measure the Earth’s magnetic field throughout flight. The vibration dampening subsystem will measure the changing acceleration as the rocket moves through its flight. The extra requirement here is that the gels need to be contained without leaking so that other subsystems would not be damaged. The last requirement was for all the subsystems. All three of the subsystems, 6 microcontrollers, need to record all of the data in files for their respective sensor.

3.0 Payload Design

The payload went through many iterations before it arrived at the final design. This year two of the subsystems were the same as last year, the magnetometer and muon detector, so minor adjustments were made to the design in terms of those elements.

The heritage elements were mounted to the top of the mounting plate while the vibration dampening subsystem was mounted to the bottom. This year the magnetometer was not in a Faraday cage and, instead, was soldered directly to the data logging shield which was attached to the Arduino. The decision about this was made after testing the magnetometer inside and outside of a cage. The results showed that having a Faraday cage made no difference. The MAG3110 IC was chosen because it was easy to obtain and it had been used by teams in the past, so the team was familiar with how to use it and knew that it worked.

The muon detector design was influenced by the previous year’s detector. The muon detector and its electronics were contained in a 3D printed container that was screwed directly to the mounting plate.

For the vibration dampening system, the team designed and 3D printed a containment unit to ensure gels would not leak and potentially damage the other subsystems. The containment unit consisted of a rectangular container with three compartments, one for each of the three gels. The cover of this container was epoxied for a tight seal and then a
secondary containment unit covered and attached to the container holding the gels. The secondary containment was also epoxied to ensure that there was no leakage.

The H3LIS331DL accelerometer was chosen because it is a low-power high-performance triple axis accelerometer. This accelerometer can measure $\pm 100$ G, which was more than enough for this experiment. It is also small, lightweight, and easy to use.

4.0 Student Involvement

Shreeya Desai (Biology 2021) designed and produced the 3D-printed components of the payload, organized the team, and helped with full system integration.

William Elliman (Computer Science and Physics 2020) soldered the muon detector and magnetometer, helped with full system integration, and provided invaluable knowledge from his past experience in RockSat-C.

Victoria Loshusan (Computer Science 2020) soldered the accelerometers and helped with full system integration.

James Truley (Physics 2020) planned and organized the outreach program.

5.0 Testing Results

A. Integrated Subsystem Testing Results

1. Muon Detector

   a. Apparatus: The Muon Detector consists of a 5 cm x 5 cm x 1 cm slab of solid plastic scintillator instrumented with a silicon photomultiplier (SiPM) to detect scintillation light emitted from charged particles as they pass through the scintillator. The signal from the SiPM is sent through a custom designed printed circuit board (PCB) which shapes the signal such that a microcontroller (an Arduino Nano) can measure the time and amplitude of the SiPM signal. An Arduino Nano is used to measure the pulse amplitude and record the count number, time of the event, temperature, and detector dead time. The threshold for a signal from the SiPM to trigger the data acquisition can be adjusted in the provided Arduino software. The detector can be powered by a USB Mini to USB connector. (from Cosmic Watch Muon Detector)

   b. Methods: The detector was assembled and powered on for several days to obtain datasets to check functionality.

   c. Results: The graph below shows all the events and the time in milliseconds of occurrence. The graph shows a detection rate of 0.00101 muons per millisecond (or about 1 count per second per 25cc active area) which is consistent with past year’s ground data.
2. Magnetometer
   a. Apparatus: A MAG3110 from SparkFun, SD card shield, and logic level converter connected to a Spark Fun Red Board to record Magnetic Field data.
   b. Methods: A magnet with known strength was moved to specified distances from the magnetometer to confirm accurate readings. The magnet was then left for long periods of time so we could confirm that the extended magnetic field would not change the output.
   c. Results: The graph below shows the results.

3. Vibration Dampening (Accelerometer)
   a. Apparatus: A H3LIS331DL Triple Axis Accelerometer from SparkFun, a 1141 data logging shield from Adafruit, an SD card, a logic level converter, and anArduino Uno was used to record and preserve data.
b. **Methods:** An accelerometer was moved along the x, y, and z axes in three different gel mediums to ensure data was recorded and preserved along all axes accurately.

c. **Results:** The graphs below show the results.

![Figure 1](image1.png)  
**Figure 1.** Accelerometer tested with epoxy coating (trial 1). X-axis is blue, y-axis is red, and z-axis is green.

![Figure 2](image2.png)  
**Figure 2.** Accelerometer tested with epoxy coating (trial 2). X-axis is blue, y-axis is red, and z-axis is green.
Figure 3. Accelerometer tested with epoxy coating in water (trial 1). X-axis is blue, y-axis is red, and z-axis is green.

Figure 4. Accelerometer tested with epoxy coating in water (trial 2). X-axis is blue, y-axis is red, and z-axis is green.

Figure 5. Accelerometer tested with epoxy coating in water (trial 3). X-axis is blue, y-axis is red, and z-axis is green.
6.0 Mission Results

Muon

To call this mission a success, the muon detector needs to have recorded and preserved counts of muons as altitude increased to the SD card. This was achieved by our preliminary results analysis. Based on the files from the SD card, the muon detector worked. An initial plot of the raw data below shows the muon counts increased dramatically right after the rocket launched. Figure 2 shows the time difference between counts. The graph shows a decrease in the time between counts as the rocket went up and an increase as the rocket fell back down. We are concerned about what this graph shows because during the high altitude flight the detector was picking up muons vary fast and
the time between counts was very small. The time difference between some of these are less than 25ms which is very close to the average deadtime of the detector at 18.6ms. The deadtime is the time that the detector is unable to detect muons because the Arduino is busy writing data to a file or doing other small calculations.

Figure 1. Total muon count as the rocket went up. The red line is launch and the green is the highest point.

Figure 2. Time differences between counts.
Magnetometer

To call this mission a success, the magnetometer needs to have recorded and preserved data as altitude increased to the SD card. Our prediction was that the magnetic field would weaken as altitude increases. Adding in lines to show when the rocket launched and when it reached its highest point, the graph becomes easier to read. Figure 4.1 shows the important section of time, when the rocket was going up. It is clear that the magnitude of the magnetic field decreases slightly even with all of the other interference.

![Raw data from magnetometer on the x, y, and z axes.](image)

**Figure 3.** Raw data from magnetometer on the x, y, and z axes.
To calculate the magnitude of the magnetic field, the magnitude of each axis was treated as a vector. These components of the total vector were then squared, added together, then square rooted.

**Dampening**
To call this mission a success, the accelerometers need to have recorded and preserved data to the SD cards. Our prediction was that the gels will be effective in dampening vibrations, more specifically, that Jell-O will be the most effective followed by hair gel and honey. Based on the graphs that were generated from the data collected during the launch, Jell-O was the most effective in dampening vibrations. The control moved the most from zero on two of the three axes, as seen in Fig. 5. The x axis of hair gel was inverted compared to the x-axis of the control and Jell-O. Comparing the magnitudes of acceleration for hair gel and Jell-O shows that Jell-O was only slightly more effective in dampening the vibrations from the rocket. The magnitudes of both gels was less than control, so both were effective and damped vibration almost equally.

The accelerometer that was submerged in honey did not collect data. On visual inspection we found that all the wires leaving the containment box were intact and connected properly.

![Figure 5](image_url)

**Figure 5.** Raw data from the accelerometer mounted to the plate and the magnitude of acceleration. The red line is launch and the green is the highest point.
Figure 6. Raw data from the accelerometer in the hair gel and the magnitude of acceleration. The red line is launch and the green is the highest point.
Figure 7. Raw data from the accelerometer encased in Jell-O and the magnitude of acceleration. The red line is launch and the green is the highest point.

To calculate the magnitude of the acceleration, the magnitude of the each axis was treated as a vector. These components of the total vector were then squared, added together, then square rooted. Magnitude of acceleration was much greater for the control than for the gels indicating dampening effect of the gels.

7.0 Conclusions

Overall, our subsystems collected data for four hours and our batteries powered the payload for the complete time. All sensors except one accelerometer gave readings, there weren’t any loose parts upon inspection of the payload, and the SD cards were still intact after flight. We still need to consider our payload partners (SIT) as well, and think about whether or not their heat element had an effect on our payload.

To investigate the cause of the failure in the vibration dampening subsystem the SD cards from the launch were taken from the various subsystems and the payload was turned on with a new SD card in the data logging shield that corresponded with the accelerometer in honey. Then the payload was turned on and moved on each axis. The
SD card collected and saved data during the test. Next, the test SD card was replaced with the SD card used during the launch to verify that the SD card was not the cause of the failure. The SD card collected and saved data during the test. The cause of the failure of the accelerometer submerged in honey was most likely that the SD card slipped out of position at some point before the launch.

The Outreach program that we ran for the Geneva Middle School students went on for 10 weeks. Through teaching them about the many fields of STEM, and collaboration with each other, we were able to bring a small part of our mission and the excitement of a NASA rocket launch to them and we were able to experience what it is like to set up lesson plans that are educational but also engaging.

8.0 Potential Follow-on Work

This mission could continue with all three subsystems. With the muon detector and magnetometer, data could be collected again to compare against previous years. The muon detector is in a constant state of refinement. With the dampening subsystem, additional gels and liquids could be tested to improve our current models on dampening vibrations from a rocket. Since only three gels were tested during this experiment, the possibilities are endless and could help to design new technology for future flights. With our Outreach program, we hope to expand it to run for more than 10 weeks, while also getting more students involved.

9.0 Benefits to the Scientific Community

The data collected from the muon detector and magnetometer provides multiple benefits to the scientific community. Research about cosmic radiation is relevant to astrophysicists, astronomers, and particle physicists. Comparing our data against other years, we have been able to improve our methods of pulse-height analysis and modeling the geosphere. Information that we gathered can inform future designs of these types of detectors, either to enhance the detection of general cosmic radiation, or to refine the detector’s ability to discern muons from other particles. These experiments also allowed us to further our own experience in designing and following through with a scientific investigation. We are all interested in future careers in our respective scientific fields, so this exposure has helped us to gain knowledge of practical skills as well as how to share data with a wider community of peers. This mission helped to promote our individual interests in STEM, which will be another benefit to the scientific community as we will all be valued contributors one day hopefully. Having the Outreach program, we helped younger students understand that there are many careers and opportunities available to them in STEM fields.
10.0 Lessons Learned

From this experience, we learned about funding, organization, communication, and deadlines.

Before any project can begin, funding needs to be secured. This was a major problem throughout the entire year as we had a new administration at our school that was not familiar with our project or the funding it needs to be successful. Because of this, we had to present to our student government, student activities, and Dean’s offices to secure funds. This required written proposals, presentations, budget outlines, and other countless forms. Regardless, we were able to persevere and acquire adequate funds to participate in this project. Since we made strong connections with our administration, student government, student activities, and Dean’s offices this year, future teams should have an easier time securing funds for their projects. Now we know that the money should be addressed first, so there aren’t as many worries throughout the year about making all the payments.

Organization is essential in any project. We wanted to make sure we ordered all parts for the payload early, so we would have ample time for testing. In addition, we wanted to make sure we had our documentation ready for the binder by keeping organized notes and a work log throughout the year. Because everything was well-managed this year, we had accurate records and didn’t have any problem once arriving to Wallops. Integration and check-in were passed with flying colors. We will preserve these notes for future teams, so it will help their project progress smoothly as well.

Communication is important as we learned this year. Because we didn’t always convey when we needed help or something was unfinished, we missed deadlines set by our advisors in order to complete everything on time. This then offset our deadlines set by COSGC and NASA, so we were always finishing things last minute. Eventually, we learned to communicate better to accomplish items on time, but the project would have progressed more smoothly if we had met deadlines from the beginning.

11.0 Appendices

GSAT-3: Hobart and William Smith Colleges RockSat-C Outreach Program

The third iteration of our Outreach Program titled GSAT-3 was planned from our initial meeting back in September of 2018. The tasks of the Outreach Manager were to not only come up with
experiments with the students but to also file paperwork with the proper people on campus and at Geneva Middle School (GMS) so the students from the middle school could work with those at the Colleges.

Paperwork that was filled out with the Colleges were the Youth Program Questionnaire form that authorizes minors to be on our campus with their parents/guardians permission but without them being present and a notification for a background check to be run on all members that could possibly interact with the students. Human Resources, the office that handled this paperwork also directed our group to the HWS: Minors on Campus training that needed to be completed by all members of the HWS RockSat-C group.

While these forms and trainings were being completed and filed, meetings were arranged in November with the Geneva Middle School Principal, Robert Smith. These initial meetings went into December, with information being exchanged and an outline of the program shared with faculty at GMS to get a bus schedule made and a permission form completed for the students. Right before the Spring Semester started in January, Principal Smith finalized the bus schedule and transferred correspondence over to Adrianna Kam, one of the guidance counselors at GMS. With help from Adrianna, a presentation was made for two different tech classes to pique interest in the program. On February 5th there were 5 students that had shown interest and decided to join the GSAT-3 program. These students were, Noah an 8th grader, and CJ, Lauren, Katie, and Solstice who were 7th graders. The week after on February 12th there was orientation for the program which was used to gauge how far along the students were in the sciences and as an introduction to the program with some icebreakers. The week of February 19th was President’s Week break for the GMS students so that time was used as finalizing their permission forms from their parents so that they may visit the college campus.

With all preparations completed, February 26th was the first meeting that involved a hands-on experiment. The topic was focused around magnetism and learning about how the world would not exist without a magnetic field to protect us. The behavior of magnets was also discussed and experiments like creating a magnetic field with a nail and wire along with demonstrating induction. The week after, March 5th was canceled because only 1 of the students were able to attend due to the others being sick.

The week of March 12th was the Geoscience lesson. Rock samples like andesite, quartz, galena, and granite were brought in and the students were taught about the properties of rocks, like shearing, hardness etc. while also teaching them about how these rocks are mined and processed for the minerals that comprise them which are then used to craft materials for a multitude of modern needs (like panels on a rocket). Other topics in Geoscience were discussed, like oceanography and meteorology to give the students a more well-rounded experience in the field.

The week of March 18th was experiments based around Fluids and why they were important to one of our subsystems. Using a weight hanging from a spring attached to an elevated point, the students were able to see what the damping ratio is and why viscosity and density are important aspects to keep in mind with which liquid we choose.
Chemistry week for the students was on March 26\textsuperscript{th} which involved more hands-on experimentation. By using glow sticks, hot water, salt pepper, a 3:2 ethanol water mix soaked $2 bill, chemical and physical changes were shown to the students.

The week of April 2\textsuperscript{nd} was the “rocket science” capstone. The topic was geared around aerospace engineering and how space flights are planned. A scenario was created for the students giving them the opportunity to plan a mission, assemble a payload, assemble a rocket and launch it. The students called upon prior Outreach knowledge that they learned to complete the scenario. Using all the information provided, the students created and launched a rocket in Kerbal Space Program.

April 9\textsuperscript{th} was the last and final meeting for the GSAT-3 students. As part of the celebration of our last day, cookies were brought in while they were debriefed on the entire experience, going through all the topics and experiences they had. After being debriefed, a tour of the Colleges was provided giving them a bit of the history of the Colleges’ development alongside Geneva.
Figure 9. Outside of half canister showing bottom plate.
Figure 10. Top of component plate showing two battery holders (yellow) with two Energizer 9V Alkaline batteries inside each, muon containment unit with muon detector inside, and an Arduino Uno.

Figure 11. Bottom of component plate showing four Arduino Unos total and a containment unit in the middle of the plate. The containment unit contains a primary component which has three separate sections for three different accelerometers and three different gels in each. A secondary component encompasses the primary for a
Figure 12. Schematic of payload design, specifically the bottom of component plate.

Figure 13. Drawing of payload design, specifically the top of component plate.
Figure 14. Drawing of payload design, showing a side view.